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Quarterly Technical Report for:

HERMETIC EDGE SEALING OF PHOTOVOLTAIC MODULES

Contract No. DOE/JPL 956352

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ABSTRACT

This report covers work done from November, 1982, through January, 1983, on a program entitled "Hermetic Edge Sealing of Photovoltaic Modules."

The edge sealing technique is accomplished by a combination of a chemical bond between glass and aluminum, formed by electrostatic bonding, and a metallurgical bond between aluminum and aluminum, formed by ultrasonic welding. Such a glass to metal seal promises to provide a low cost, long lifetime, highly effective hermetic seal which can protect module components from severe environments.

It is the purpose of this program to develop the above described sealing techniques and to demonstrate their effectiveness by fabricating a small number of dummy modules, up to eight inches square in size, and testing them for hermeticity using helium leak testing methods. Non-destructive test methods will be investigated.

The current technical status is provided and the direction of future work is described.

SECTION 1
INTRODUCTION

This is the first quarterly technical report for JPL Contract 956352, "Hermetic Edge Sealing of Photovoltaic Modules." It covers the progress made during the period from November, 1982, through January, 1983.

It is the purpose of this program to investigate the feasibility of producing hermetic edge seals by the following process:

1. Bond an aluminum foil gasket to the perimeter of a glass sheet by electrostatic bonding. This glass sheet will become the module superstrate.

2. Encapsulate a solar cell circuit behind the glass using a standard lamination or casting process.

3. Bond the back cover, made of aluminum foil, to the foil gasket by ultrasonic seam welding.

During electrostatic bonding, negatively charged oxygen ions in the glass are bound to positively charged aluminum ions in the foil, forming a thin aluminum oxide (Al_2O_3) layer at the interface. This results in an adherent, permanent chemical bond between the glass and the aluminum. It is the combination of this chemical bond with the metallurgical bond formed by ultrasonic welding that seals the module edges, hermetically.

A typical application is a glass superstrate design module with an aluminum foil back cover, as depicted in Figure 1. Other applications include double glass design modules (Figure 2) and glass superstrate design modules with rigid aluminum back covers (Figure 3). The type to be fabricated for demonstration under this contract is the type shown in Figure 1.

The three major tasks of this program are:

ALUMINUM FOIL
BACK COVER

ENCAPSULANT

SCRIM
INSULATOR

ALUMINUM TO
ALUMINUM SEAL
BY ULTRASONIC
WELD

SOLAR
CELL

ALUMINUM TO
GLASS SEAL
BY ESB
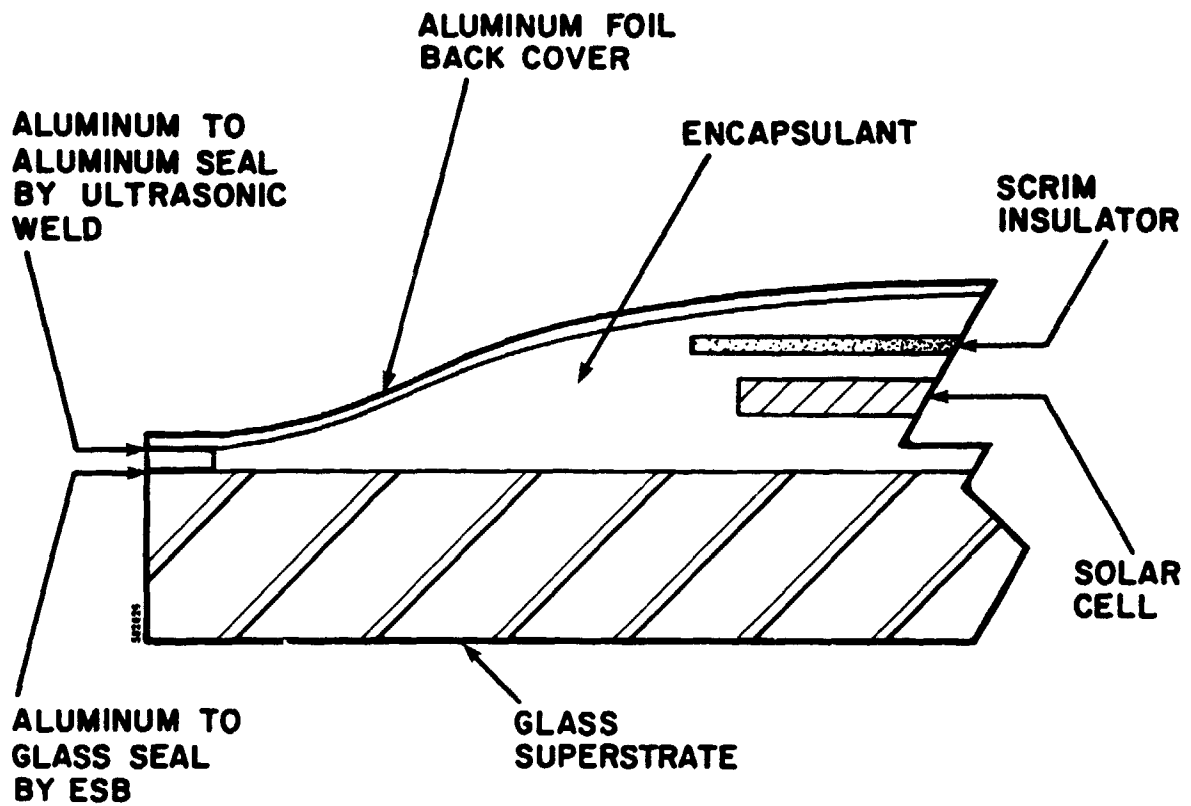
GLASS
SUPERSTRATE

FIGURE 1.   GLASS SUPERSTRATE DESIGN MODULE WITH ALUMINUM FOIL
BACK COVER AND HERMETIC EDGE SEAL.

ALUMINUM TO ALUMINUM
SEAL BY ULTRASONIC
WELD

ALUMINUM TO GLASS SEAL
BY ELECTROSTATIC BOND

ALUMINUM
FOIL

GLASS SUBSTRATE

ENCAPSULANT

SOLAR CELL
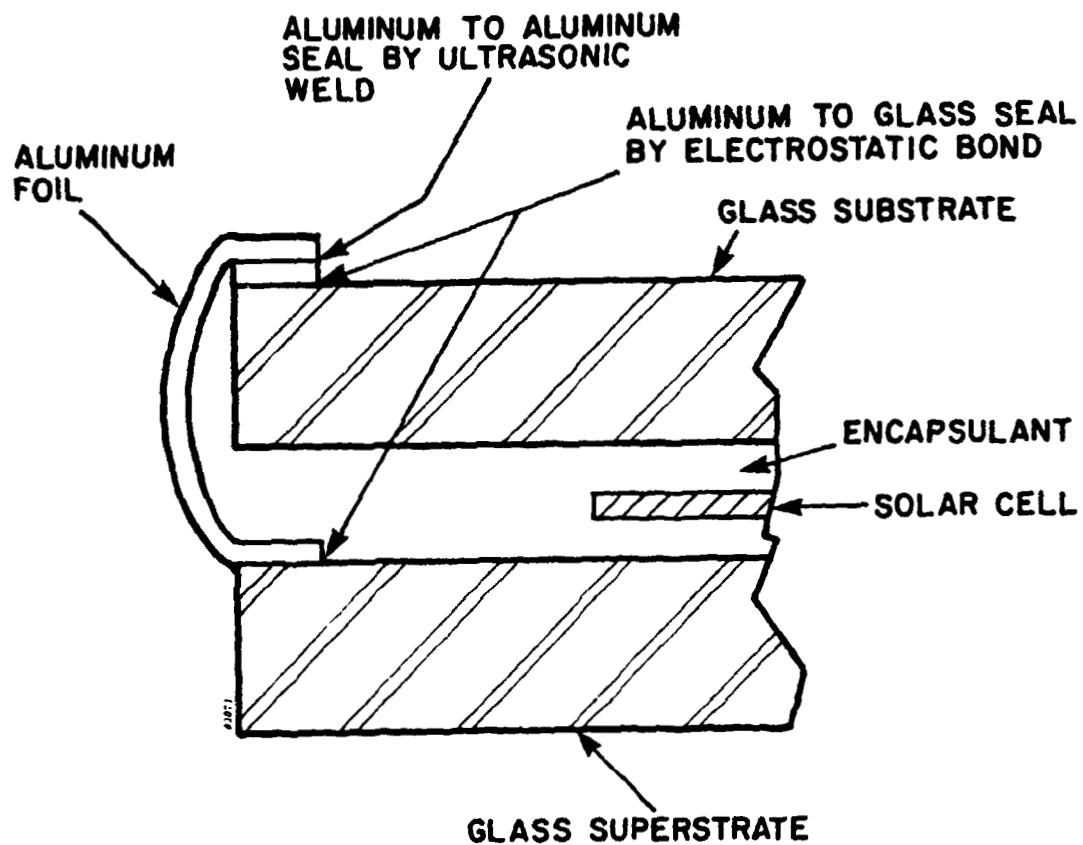
GLASS SUPERSTRATE

FIGURE 2.   DOUBLE GLASS DESIGN MODULE WITH HERMETIC
EDGE SEAL

ALUMINUM FOIL TO ALUMINUM SHEET
SEAL BY ULTRASONIC WELD

ALUMINUM
FOIL

ALUMINUM SHEET OR PAN

ENCAPSULANT

SCRIM INSULATOR

SOLAR CELL

GLASS
SUPERSTRATE

ALUMINUM TO GLASS
SEAL BY ELECTROSTATIC
BOND
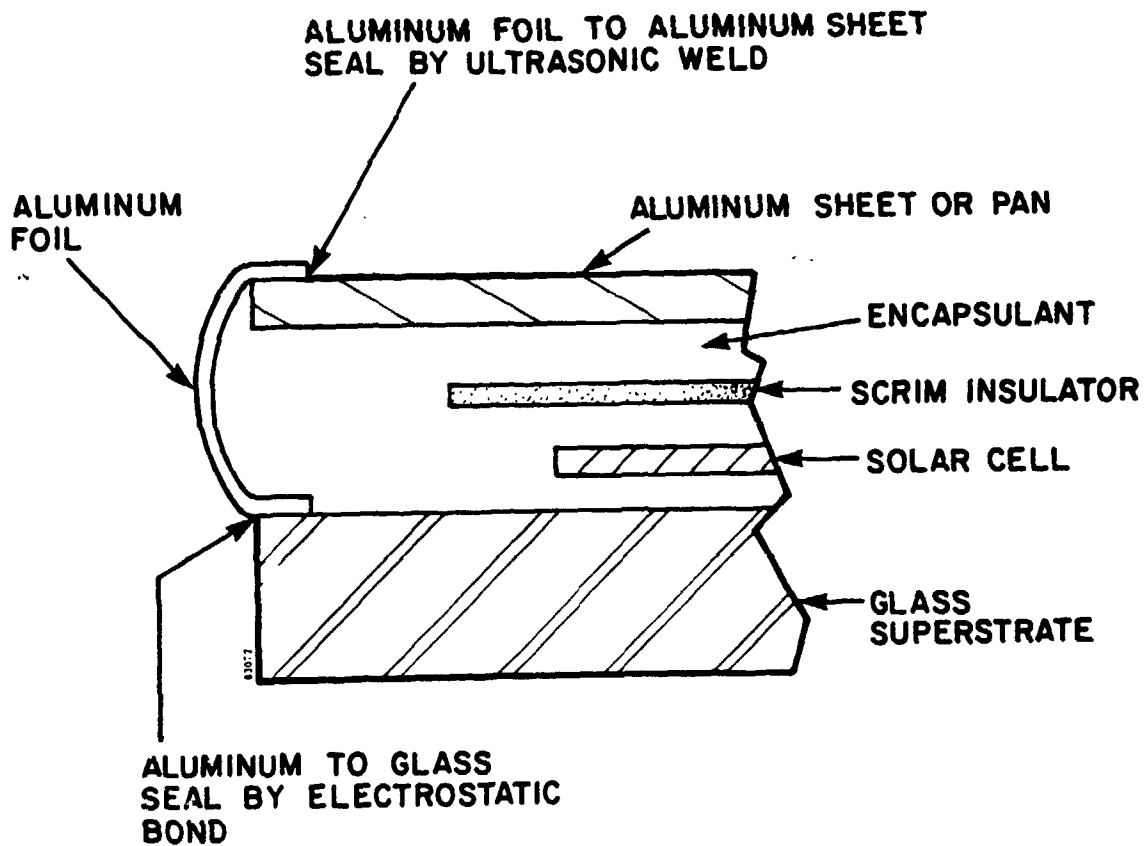
FIGURE 3.   GLASS SUPERSTRATE DESIGN MODULE WITH RIGID
ALUMINUM BACK COVER AND HERMETIC EDGE SEAL

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1. Experimentally develop an electrostatic bonding techniqu for bonding aluminum foil to glass sheet, in air at atmospheric pressure.

2. Experimentally develop an ultrasonic bonding technique to bonr aluminum foil to aluminum foil to complete the hermetic edge seal ⸲ photovoltaic module.

3. Demonstrate the effectiveness of the above stated techniques by fabricating a small number of dummy modules and testing them for hermeticity using helium leak testing methods. Methods for non-destrictive testing shall be investigated.

SECTION 2
TECHNICAL DISCUSSION

2.1 ELECTROSTATIC BONDING TECHNIQUE

It is the purpose of electrostatic bonding (FSB) to provide a glass to metal seal between the module superstrate and a foil gasket. Materials must be properly chosen and bonding in air must be developed and optimized.

2.1.1 Materials

Since the module type to be demonstrated in this program is the type shown in Figure 1, the main materials to be chosen for ESB are the aluminum foil for the gasket and the glass for the superstrate.

Ordinary annealed soda-lime-silica (window) glass was chosen for its availability and its high degree of surface smoothness. A requirement of ESB is that surfaces must have smoothnesses on the order of one micrometer or less.[1] A measurement of a typical window glass surface, using a Dektak surface profilometer, shows peak to peak heights of 40 to 80 Angstroms, with occassional irregularities as deep as 200 Angstroms (Figure 4). Soda-lime-silica glass is also easy to bond at relatively low temperature (300-400°C) due to its high sodium and calcium content: 13% Na_2O and 9.3% CaO by weight.[2]

The aluminum alloy 1100-0 was chosen for its soft temper and low yield strength. These properties minimize the residual stress at the glass-aluminum interface after bonding. The surface smoothness of the aluminum was measured with a surface profilometer, and the foil was found to have a smooth and a rough side. As shown in Figure 5, the smooth side has peak to peak heights less than 0.15 micrometers, while the rough side has features as large as 1.35 micrometers, peak to peak. This difference in surface smoothness turns out to have a significant effect on bond quality, as is described in Section 2.1.2.

A glass thickness of 3.2 mm (1/8 inch) was chosen since it is the most commonly chosen thickness for photovoltaic module superstrates. An aluminum foil thickness of 51 micrometers (2 mils) was selected because it is thick enough to survive ultrasonic welding, but not so thick that it will generate excessive stress at the post-bond glass-aluminum interface.

FIGURE 4.   WINDOW GLASS SURFACE SMOOTHNESS
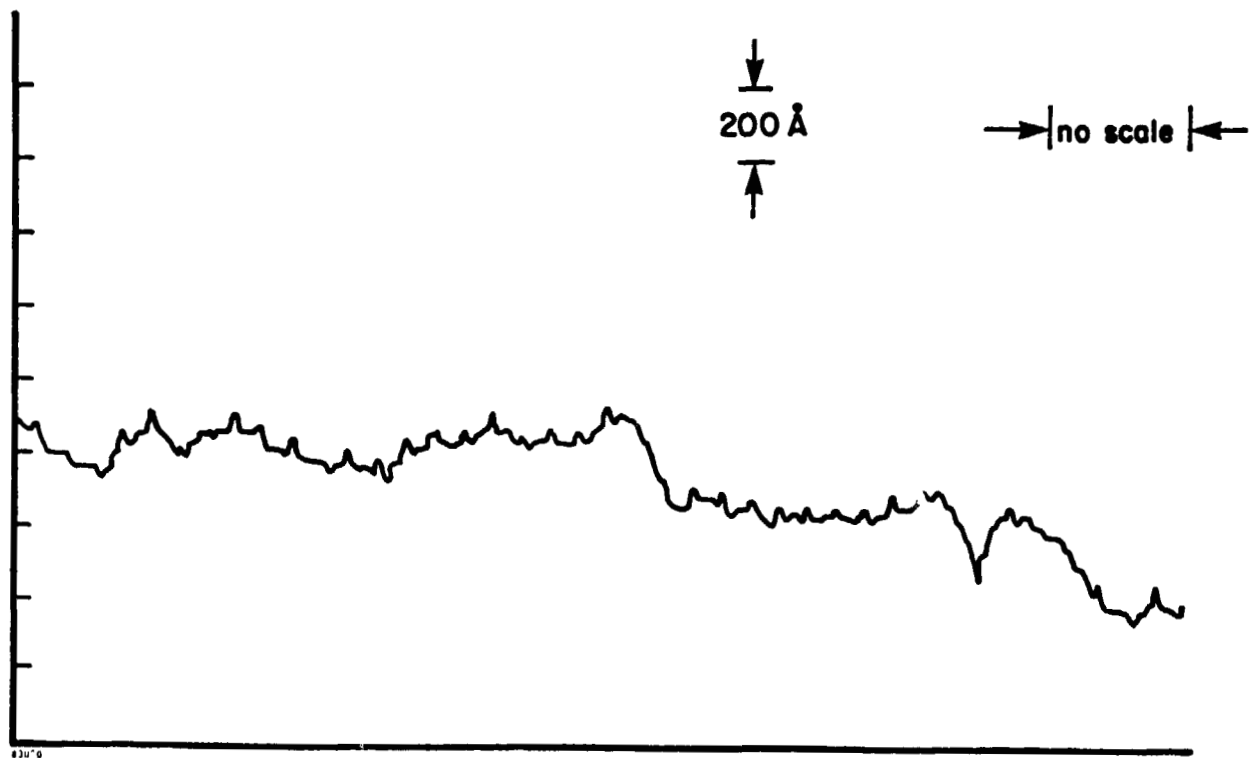
ROUGH SIDE OF 2 MIL ALUMINUM FOIL

0.5 μm

no scale

ORIGINAL PAGE IS
OF POOR QUALITY

<1.35 μm PEAK TO PEAK

SMOOTH SIDE OF 2 MIL ALUMINUM FOIL
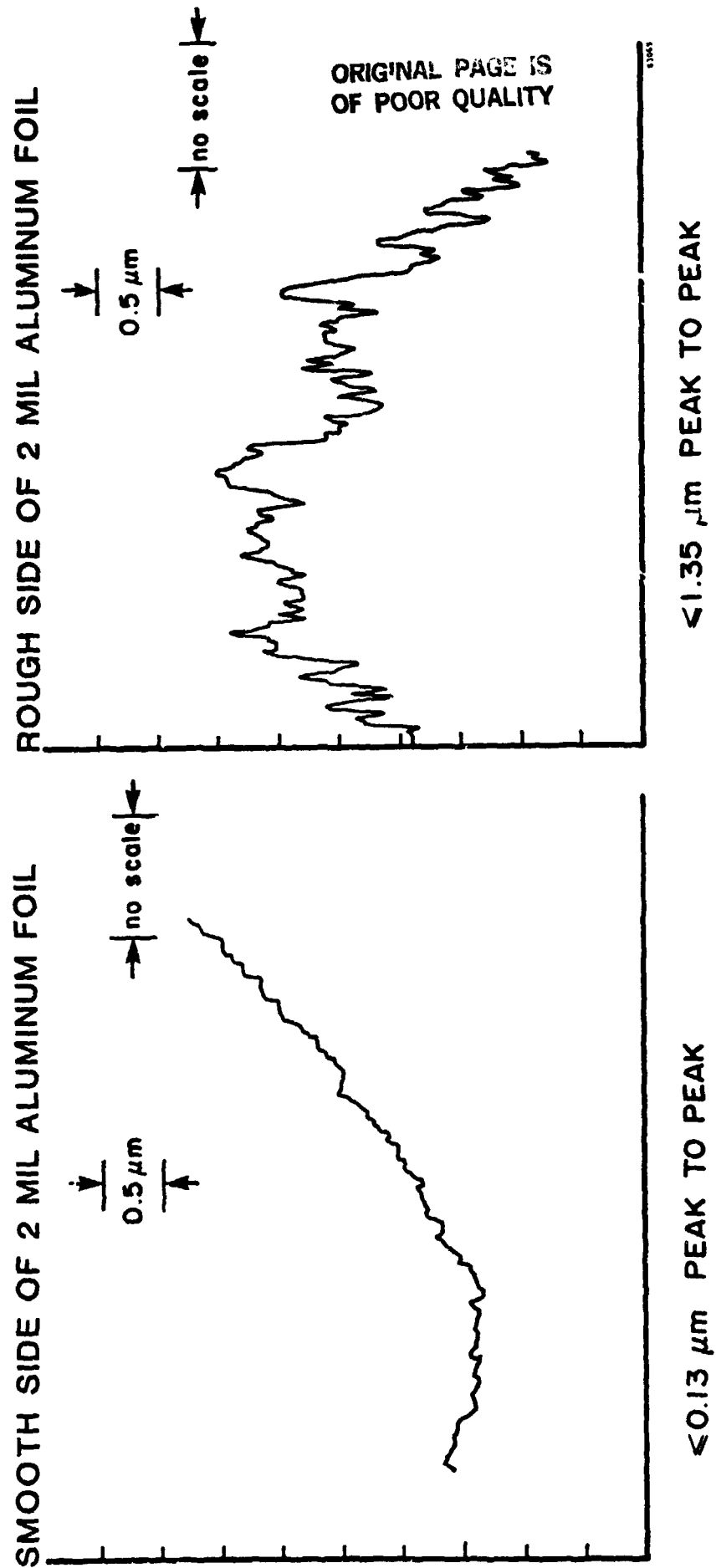
0.5 μm

no scale

<0.13 μm PEAK TO PEAK

FIGURE 5.   ALUMINUM FOIL SURFACE SMOOTHNESS

2.1.2 Optimization Experiments

A range of ESB experiments was conducted, aimed at developing a bonding process in air at atmospheric pressure. Similar aluminum foil-glass bonding had been carried out at Spire in a program to develop hermetically sealed thermal pane windows[3], but these bonds were done in a vacuum or a nitrogen environment.

The first step was to fabricate bonding electrodes suitable for bonding aluminum foil gaskets to the perimeter of an 8-inch square piece of glass. These electrodes were then used to duplicate the bonding process developed under the previous program[3] with the exception that the environment is now air, at atmospheric pressure. The development of this process in air is important because it allows for a great simplification of the bonding apparatus. The baseline bonding cycle, showing the applied pressure and voltage and the resulting induced ionic current flow, is shown in Figure 6. The bonds produced under these conditions had excellent adhesion, but a large number of small air pockets, on the order of 1 mm diameter, were trapped between the aluminum and the glass.

A series of experiments was undertaken to eliminate the air entrapment problem. Process parameters such as pressure, applied voltage, temperature and time were varied but with no significant improvement. At this time, it was realized that the aluminum had a "shiny" side and a "dull" side, and that the difference in its reflective property was probably due to a variation in surface roughness. This was verified by measurement with a surface profilometer, as described in Section 2.1.1. Inspection of the bonding experiments up to that time revealed that the more reflective, smooth side had been bonded to the glass, in all cases. The first experiment in bonding the rough side resulted in complete elimination of all trapped air pockets. The adhesion of the bond was qualitatively good, but not as strong as the bonded regions of the smooth aluminum foil bonds.
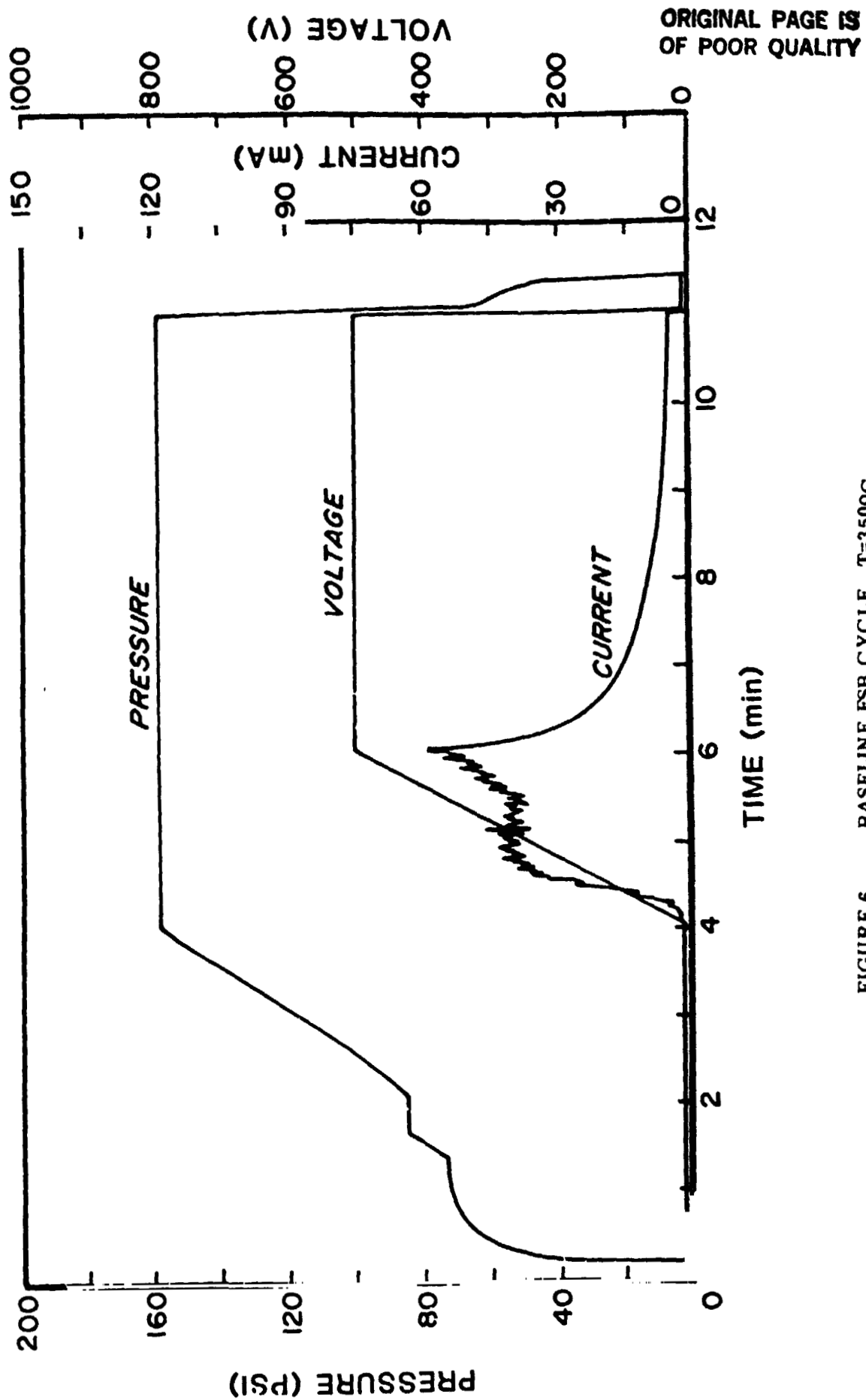
FIGURE 6.   BASELINE ESB CYCLE. T=350ºC.

An explanation for the reduction in bond adhesion of the air pocket-free bonds was deduced from examination of the bonds under moderate (52X) magnification. Figure 7 shows two photomicrographs of aluminum foil-glass interfaces, as seen through the glass. The top picture shows a typical interface created by bonding the 0.1 micrometer smooth foil to glass in air. Although there are a number of air pockets present, the region between pockets is extremely well bonded. In contrast, the bottom picture in Figure 7 shows a post-bond interface between 1 micrometer smooth foil and glass. The light areas are regions of good bonding, while the dark areas are unbonded. Although there are no air pockets, it is seen that the rougher surface foil has less percentage of total area bonded than the inter-bubble regions of the smooth foil, which results in the observed reduction in foil adhesion to glass. There is probably an optimum surface roughness, between 1.0 and 0.1 micrometers peak to peak, at which a maximum bonded area is achieved without leading to the entrapment of air in pockets.

As mentioned briefly above, there was no significant improvement to the bond quality by varying the process parameters. Consequently, the parameters have not been modified substantially from the baseline cycle illustrated in Figure 6.

The applied hydraulic ram pressure has been increased from 150 psi to 250 psi for better bond uniformity. These ram pressures translate to electrode contact pressure at the bond of 27.8 psi and 60.4 psi, respectively.

Voltages higher than 500 V were found to cause arcing across the edge of the glass due to the geometry of the process, and the air environment. Thus 500 V is a good peak voltage level.

Several methods which reduce bonding time have been incorporated into the process sequence. The five minute dwell time that peak voltage was applied in the baseline (Figure 6) case was determined to be conservative, since the induced current flow decays sharply once the peak voltage is obtained. The peak voltage dwell time has therefore been reduced to one minute. Similarly, the rate of the applied voltage (dV/dt) has been increased from 250 V/minute to 500 V/minute. These changes have led to a total reduction in cycle time of 5 minutes. A plot of the new, optimized ESB cycle is shown in Figure 8.

Smooth Surface, 2 mil Aluminum Foil
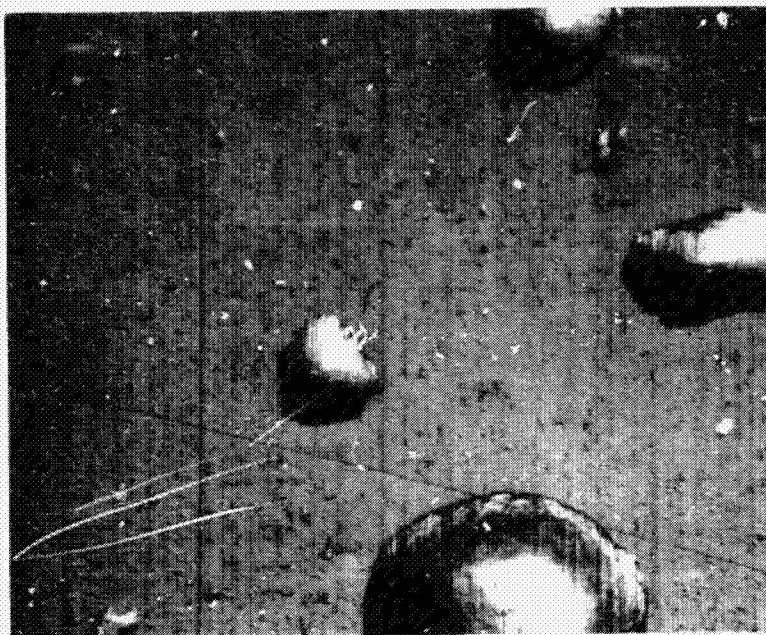
├─────── 1 mm ───────┤

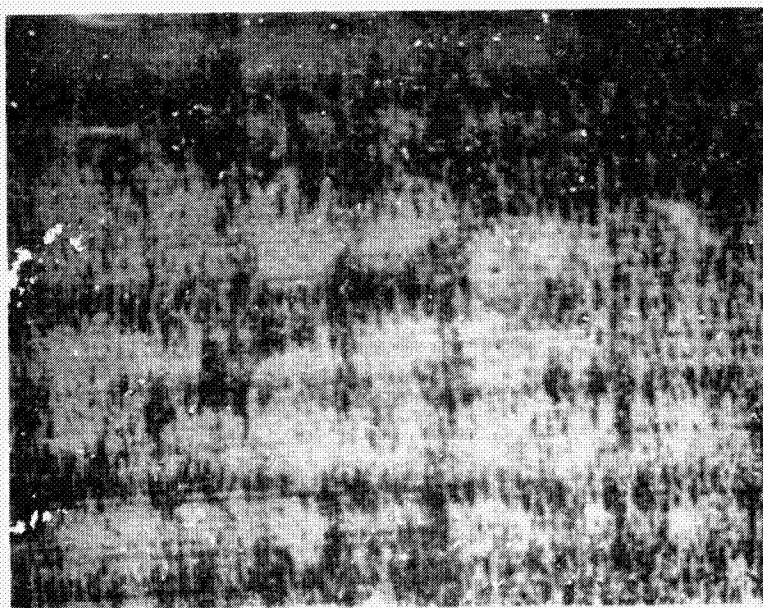Rough Surface, 2 mil Aluminum Foil

FIGURE 7.   PHOTOMICROGRAPHS OF ALUMINUM FOIL BONDED TO
GLASS BY ESB. Views are of the foil-glass interface as seen
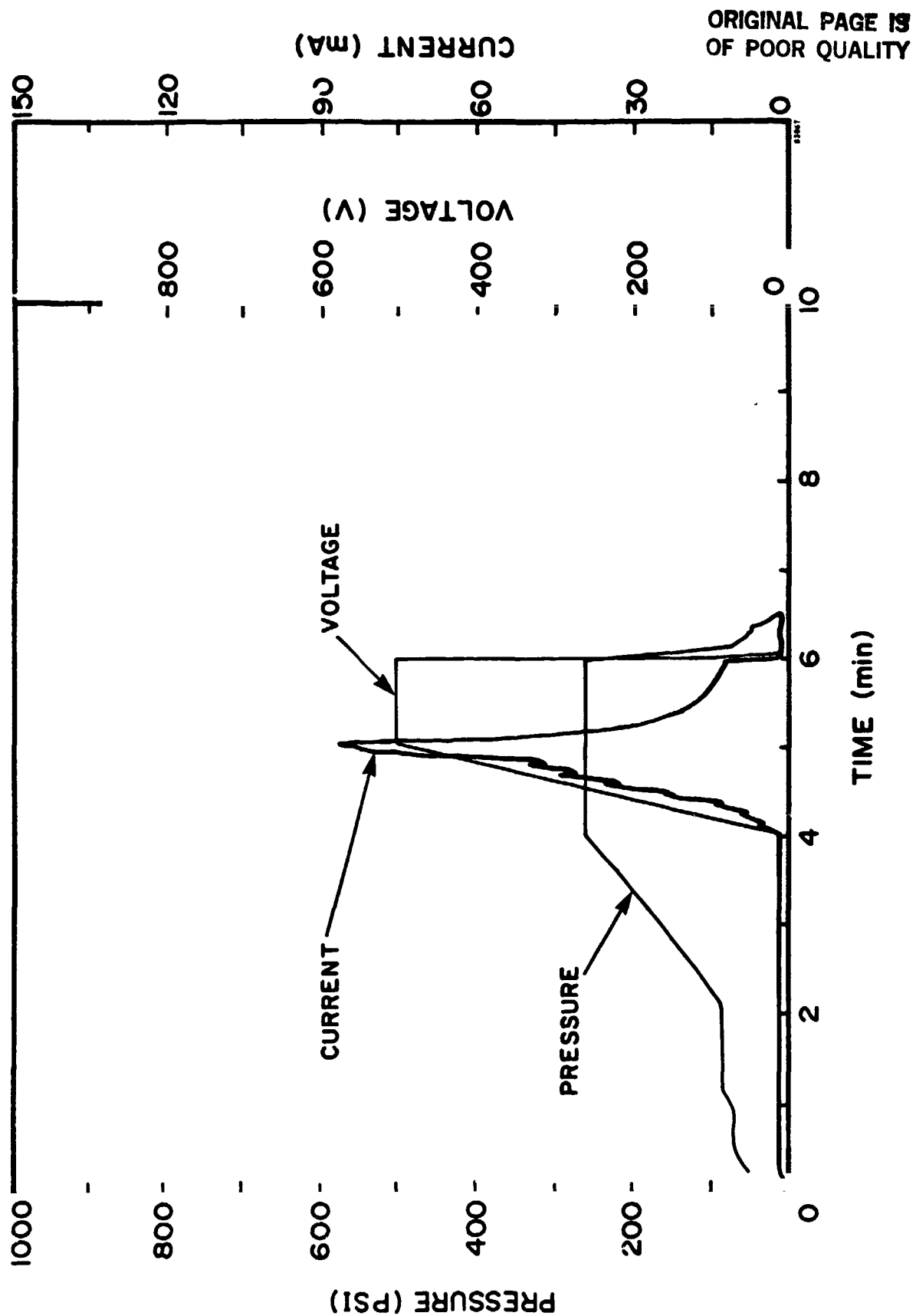through the glass. Magnification is 52X for both views.

FIGURE 8.   OPTIMIZED ESB CYCLE. T=350oC.

2.1.3 Roll Bonding Experiments

The above described ESB experiments were carried out using Spire's research electrostatic bonder, shown in Figure 9. A new technique for electrostatic bonding which has great promise for simplifying the bonding apparatus was briefly investigated. In this technique, the fixed electrode of the conventional ESB set-up is replaced by a rolling bearing electrode. This concept is illustrated in Figure 10. With such a bonder, any size glass can have a gasket bonded to it without changing the bonding electrode, and very large glass lites can be bonded without a large, precisely aligned platen press. Also, bonding with a rolling electrode might prevent the formation of air pockets observed when bonding smooth surfaces, since bonding should occur along a progressive front.

A crude experimental version of such a bonder was assembled to determine if such a technique is feasible. Adherent electrostatic bonds were achieved on both the rough and smooth sides of the 51 micrometer thick foils. The bonded interfaces were essentially similar to those shown in the photomicrographs in Figure 7. Results were, however, less reproducible than the fixed electrode results for several reasons, including, the lack of control of the roller's traversing speed, the lack of a roller electrode of the proper geometry, poor alignment and poor vertical force control between the roller electrode and the aluminum ribbon. Despite these equipment limitations, the experiment did prove the feasibility of bonding using the rolling electrode approach.

2.2 ULTRASONIC BONDING TECHNIQUE

This technique is to be used for welding a module back cover, made of aluminum foil, to the aluminum foil gasket which has previously been attached to a glass superstrate by ESB. A suitable ultrasonic seam welder was identified and purchased. We are currently awaiting delivery from the manufacturer. In the mean time, engineering drawings have been obtained from the manufacturer, allowing us to proceed with our tooling design. This tooling will allow us to register and translate the seam welding head with respect to the glass-foil assembly.

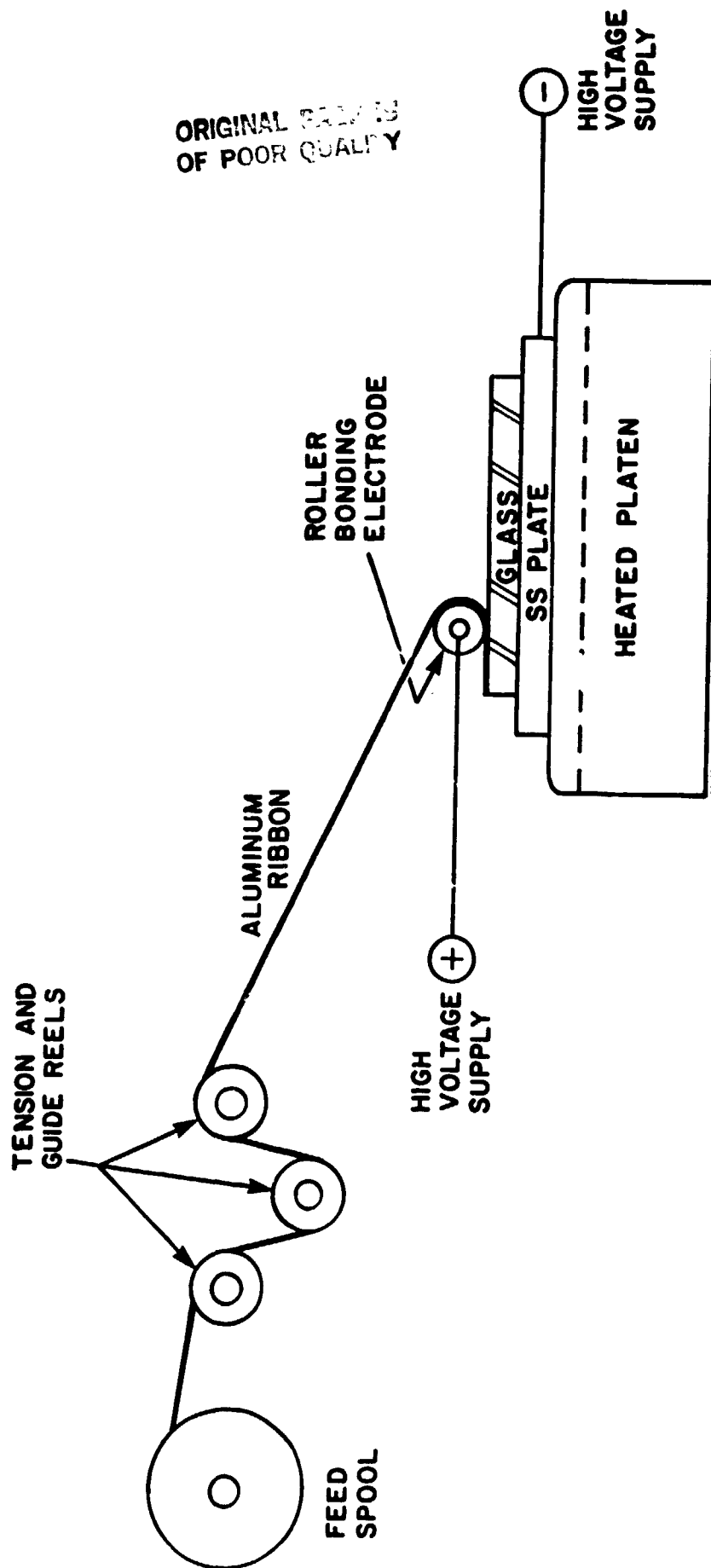FIGURE 9. SPIRE RESEARCH ELECTROSTATIC BONDER

FIGURE 10. ROLLER BONDER CONCEPT FOR HERMETIC EDGE SEALING

Several glass-foil assemblies have been fabricated by ESB. These will be used for developing the ultrasonic seam welding process. Several eight-inch square dummy modules have also been fabricated. These are of the type shown in Figure 1, and are completed except for the ultrasonic weld. Once welded they will be subjected to hermeticity testing as described in Section 2.3.

2.3   DEMONSTRATION OF DEVELOPED TECHNIQUES

The effectiveness of the electrostatic bonding and ultrasonic welding techniques in providing a hermetic seal will be demonstrated by subjecting a small number of dummy modules to leak testing. When this task was conceived it was imagined that such testing would involve penetration through the foil or the glass to introduce helium inside a dummy module. Fortunately, however, a non-destructive test method for leak testing heremtic seals was discovered in the Book of SEMI Standards.[4] The specification is MIL-STD-883B, Method 1014.4, Seal.

Once the eight-inch square dummy modules discussed in Section 2.2 have had their back covers ultrasonically welded to their edge gaskets, they will be tested according to the above referenced specification. One of the test conditions A1, A2 or A4 will be followed for tracer gas helium fine leak testing, while test condition C will be followed for fluorocarbon gross leak testing. Helium, fluorocarbon detector fluid and fluorocarbon indicator fluid have been purchased. All of the equipment required to execute the fine and gross leak tests has been found to exist at Spire, and will be made available for this program.

SECTION 3
CONCLUSIONS

The electrostatic bonding development task of this program is now complete. Two mil thick aluminum foil gaskets have been successfully bonded to 1/8 inch thick window glass in an air environment. Bonding parameters have been optimized. An initial, unexpected problem of air entrapment in millimeter size pockets has been solved by choosing an aluminum foil with a surface of appropriate roughness. There is an optimium aluminum surface roughness between 1.0 and 0.1 micrometer peak to peak at which a maximum bonded area is achieved without leading to the formation of air pockets. The hermeticity and the environmental survivability of such glass-aluminum bonds remains to be tested.

A novel rolling electrode approach to fabricating electrostatic bonds was conceived. Preliminary experiments have proved this approach to be feasible. Such a method allows for simplification of the ESB apparatus, since any size glass can be bonded without changing the electrode, and very large glass lites can be bonded without the need for a large, precisely aligned hydraulic press.

Ultrasonic welding equipment has been identified and ordered. Tooling needed to register the glass and foil with respect to the welding head is being designed.

A non-destructive test method (MIL-STD 883B) which allows for helium fine leak testing and fluorocarbon gross leak testing of heremtically sealed packages has been identified. The necessary equipment to perform this test has been found to exist at Spire, and test materials (helium and fluorocarbons) have been ordered.

SECTION 4
RECOMMENDATIONS

Several promising areas for future investigation have been identified during the course of this program. This edge sealing technique can be extended to other module design types, as illustrated in Figures 2 and 3. Also, the electrostatic bonding work done so far has been done with 1/8" thick annealed soda-lime-silica (window) glass. Other types of glasses should be investigated, such as tempered glass, glasses of different thicknesses, and glasses with low iron oxide (Fe_2O_3) content.

A most interesting new concept is the use of a rolling electrode for bonding aluminum ribbon to glass by ESB. Although the feasibility of this concept is proven, reproducibility can only be demonstrated by constructing a specially designed electrostatic bonder for this purpose.

It is also recommended that, in addition to hermeticity testing, dummy modules fabricated by the technique described in this report be subject to environmental testing, such as the JPL Block V series of tests. Such testing is necessary to establish confidence in the quality and lifetime of these hermetic seals. Accelerated environmental tests would also prove useful in comparing degradation of modules with hermetic edge seals against modules with conventional edge seals.

SECTION 5
REFERENCES

1.   T.R. Anthony, "Anodic Bonding of Imperfect Surfaces," GE Technical Information Series, Report No. 82CRD293 (1982).

2.   D. G. Holloway, "The Physical Properties of Glass," Wykeham Publications, London (1973), p. 2.

3.   Spire Corporation, "Low Heat Loss, Long Lifetime, Low Cost, Hermetically Sealed Thermal Pane Window Construction," Final Report for DOE Contract DE-AC02-81ER 10863 (1981).

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